PROTECTIVE DEVICES CO-ORDINATTION TOOLBOX ENHANCED BY AN EMBEDDED EXPERT SYSTEM - MEDIUM AND LOW VOLTAGE LEVELS

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SUMMARY

Industrial utilities are protected by a variety of protective devices that no incidents can cause damage to the installations/utilities. Good facilities power quality starts with a reliable power distribution system. Apart from the reliability and rapidity of the protection system, selectivity is one of the essential aspects of power quality. A lack of selectivity leads to inappropriate tripping of the protective devices, in other words things are cut out that are not necessary for eliminating the fault. Incorrect tripping can cause part of the installation to be out of action unnecessarily. This causes loss of productions during the time it may take to restart the installation that may cost a lot of money. Hence, it is suggested in this proposed work to design and implement a power system devices co-ordination toolbox using MatLab6.0 facilities. Executable versions may be obtained with the relevant DLL files and figures also can be produced after generating C/C++ plus header files code. The main outputs are obtained on log/log graphs through smart interfacing dialog windows. This graph should include but not limited to the following: motor starting curve, cable damage curve(s), transformer withstand short circuit capabilities and inrush current point indication as well. Overcurrent tripping characteristics (IEC255/BS142 standard curves and ANSI/IEEE242 as well) enhanced by the relay's major manufacture's databases over the world, fuse tripping curves, and circuit breakers tripping curves are detailed and analyzed. To enhance the protective device selectivity software, a set of rules are embedded to result a golden advise to minimize the trails to speed fitting the correct upstream selective curve with the down stream tripping curve. Rules are in the form IF ----and/or ---- THEN -----. Finally the proposed system is tested and verified on a practical distribution system and showed to be reliable, friendly user interface and easy tool for protective device co-ordination.

INTRODUCTION

The coordination study evaluates current transformer ratios, protective relay characteristics and settings, fuse ratings, low-voltage circuit breaker ratings, characteristics, and trip settings [1-4]. The study provides the information needed to design a system with the optimum level of protection and selectivity in coordination of devices. When coordinating a new system into an existing electrical system, the protective device study ensures that the two systems are coordinated.

Preparation of such discrimination studies can be a time consuming task involving the drawing of graphs based on extensive consultation of manufacturer's data [1-5]. So, it is suggested to develop and design a toolbox for power system device coordination to drastically reduce the time spent on the protective devices discrimination studies. Generally three common methods are utilized to give the correct coordination by [2-3]:

- Discrimination by time.
- Discrimination by current.
- Discrimination by both time and current.

An expert system has been developed for recording and modeling knowledge of power engineering experts in the domain of protection coordination for industrial power system [5]. Also, commercially powerful programs [6,7] are available for relay coordination. These softwares have no type of expert rules to aid the users in case of confusion or consultation request. So, it is suggested to develop and implement a toolbox for power system coordination with good graphical user interfaces integrated with some type of expert rules. Hereunder, a brief overview of the proposed toolbox with the relevant modules will be presented and discussed.

TOOLBOX OVERVIEW

It is convenient to have the main core for a big program of any kind be organized as a sub-modules to be activated by selecting the corresponding item from the main menu and returns for another selection(s). Hereunder in briefing of device time/current curves creating will be demonstrated and presented. The toolbox consists of the following modules:

- Cable damage curve module.
- Motor Starting Module.
- Transformer Withstand Curve.
- Overcurrent modules.
- Fuses.
- Circuit breakers.
- Thermal overload module.
- Module of text and curve processing.
- Saving format and graphical module and other graphical facilities including coordinates.

Proposed protective device coordination toolbox was developed using MatLab Statements and running under PC [8].

Cable Damage Curve

On the basis that all heat is absorbed by the conductor metal and there is no heat transmitted from the conductor to the insulation material. The temperature rise is a function of the size of the metallic conductor, the magnitude of the fault current, and the time of current flow [2-3]. These variables are related by the following formula in (1) and (2).

$$\left[\frac{I}{A}\right]^2 t = 0.0125\log\left(\frac{T_d + 228}{T_o + 228}\right) \qquad \text{For copper} \qquad (1)$$

$$\left[\frac{I}{A}\right]^2 t = 0.0297\log\left(\frac{T_d + 234}{T_o + 234}\right) \qquad \text{For Aluminum} (2)$$

Where I= short circuit current (A)
A= cross section area in c. mils
T= short circuit time (S)
T_d= damage temperature
T_o= operating temperature.

Various types of insulation materials operating and damage temperatures are stored in the data bases library for this module. Among these different insulation materials such as XPLE, EPR, PVC, Paper, Rubber, Silicon Rubber, thermoplastic, and Bare AL/CU while, new material databases may be added/removed very easily or fed directly through editor boxes. Also, cable sizing with both AWG/MCM and mm^2 is utilized.

Transformer Z-Curve

Withstand/damage Z-curves of distribution transformers defines how much current a transformer can withstand and for how long. These curves relate both thermal and mechanical damage and are defined by different fault conditions. Three ANSI categories for distribution transformers are considered and analyzed according to ANSI 242 documents for frequent and unfrequent faults. Maximum short circuit current (I_{sc}) may be calculated by dividing the transformer rated current by the per unit impedance and then calculate the constant K for the following equation (3) at t=2 seconds.

$$K = I_{sc}^2.t \qquad (3)$$

Transformer magnetizing inrush current is approximately 8 to 12 times of full load current for a period of 0.1 second with transformers of sizes 500 to 2500 kVA. While for transformers with ratings above 2500 kVA is considered 20 to 25 times of rating current for a period of 0.01 second. Different winding connections are considered to achieve the ANSI factor shifting that is based upon the primary and secondary winding connections.

Motor Starting Module

The energizing of motors causes a starting current of initially 5 to 8 times of rated current (locked rotor current). A typical time/current curve result from the proposed module for motor starting for an induction motor of 30 HP/44 A, 400 V, 5 P.U. of name plate current as starting current (Direct on Line) with 8 seconds acceleration period is shown in Fig. (1).

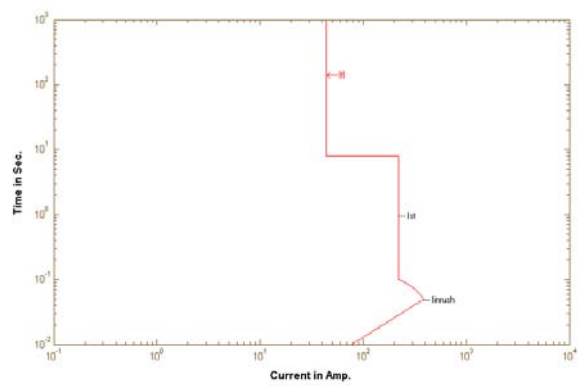


Fig. (1) Typical t/I curve of motor starting

Inrush current value may be calculated from (4).

$$I_{inrush} = 1.6*1.1*I_{starting} \qquad (4)$$

Where: 1.1 is a safety factor and 1.6 is inrush factor.
The basic methods of induction motors starting are utilized/programmed that include direct on line, star/delta, auto-transformer (50%, 65% and 80% tapping) and reactors/resistor starting. NEMA/NEC code

for motor starting letters are presented and compiled as well.

Fuses Tripping Curves

Fuses were undoubtedly the first form of protection to be used in electric systems, and they have continued to be used in increasing numbers up to present day. The operating time of fuse is a function of both the pre-arcing and arcing time of the fusing element, which follows an I^2t law. So, to achieve proper selectivity between two fuses is series, it is necessary to ensure that the total arcing I^2t value taken by downstream fuse is less than the pre-arcing I^2t value of the major fuse.

Overcurrent Protection Characteristics

Overcurrent protection is considered the main protection for the medium voltage distribution networks. There are four standard curves of IEC, extremely, very, normal and long time inverse. The relationship between current and time complies with the standards BS142 and IEC255-4 and may generally be expressed as shown in (5).

$$t = \frac{B.TSM}{\left(\frac{I}{I_>}\right)^K - 1} \qquad (5)$$

Where t= operating time (S)
I= current value (A)
TSM= Time Setting Multiplier
$I_>$= set current Value (A).

The degree of curve inversely is determined by the values of constants K and B as shown in table (1)

Degree of inversity	K	B
Normal Inverse (NI)	0.02	0.14
Very Inverse (VI)	1.0	13.5
Extermely Inverse (EI)	2.0	80.0
Long Time Inverse (LTI)	1.0	120

Table(1) K & B Standard values

Some relays have special time/current characteristics to provide a high degree of selectivity like RI and RXIDG are presented and featured. Normally the time setting multiplier ranges from 0.05 to 1.0 in step of 0.05 or as typically given by the manufacturers.
Overcurrent tripping characteristics (IEC255/BS142 standard curves and ANSI/IEEE242 as well) enhanced by typical relay's major manufacture's databases over the world are detailed and analyzed. Among of these several manufacturers of relays including but not limited to ABB, GE, Schneider, CEE, and Siemens, etc … had been programmed/compiled and stored to enhance the program capabilities. Recommended time setting can be calculated through this proposed module based on the relay characteristic, operating time and short circuit level. Different relay characteristics may be obtained with a limited number of selections done very easily without needing to sophisticated data from manufacturers.

Discrimination Time Margins

The total interval required depends on the operating speed of breakers and the relay performance. In general the time margin interval of 0.2-0.4 second is reasonable.
The time interval between the operation of two adjacent protective devices (relays, breakers and/or fuses) depends upon number of factors:

1. The fault current interrupting time of the breaker.
2. The overshoot time of the relay.
3. Errors.
4. Final safety margin on completion of operation.

The minimum grading time interval, t', may be calculated as shown in (6).

$$t' = \left[\frac{2E_R + E_{CT}}{100}\right]t + t_{CB} + t_{OV} + t_S \qquad (6)$$

Where
E_R = Relay timing error to IEC255-4 %
E_{CT}= Allowance of CT error %
t_{CB}= CB interrupting time (S)
t_{OV}= Relay Overshoot time (S)
t_S= Safety Margin (S)
t = operating time of the relay near the fault (S)

Electronic and microprocessor-based relays are more accurate than electromechanical relays, which means that the discrimination time between relays can be reduced. For many breaker designs the interrupting time is typically 0.1-0.15 S, but the equivalent time for vacuum breakers is only 0.07 S. when coordinating relays with downstream fuses, the circuit opening time does not exist.

Consultation/Expert System Module

The main role of this proposed expert system module is to aid/help the user to rapidly finalizing the coordination study.
A set of expert rules for the coordination of protective devices either relays, fuse or combinations of them was developed based on the experience gain in this

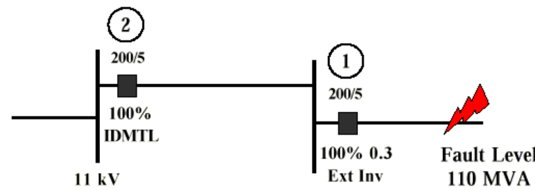
specific domain of problem. Rules are in the form IF-- and/or -- THEN advise by the final conclusion. These rules deal with a series protective elements for achieving the selectivity study. As an example for such type rules i.e. *if a minor and major fuses are to be graded then the current ratio between major fuse to minor fuse should be greater than 2 to be correctly graded*.
The user select the down-stream condition and the up-stream condition via a popup buttons and immediately the conclusion is presented/resulted to be taken into considerations.

Verification of Applicability

In the development and implementation of this toolbox for protective device coordination, special attentions were paid to the user interface facilities. User interface (UI) is a key issue in the case of computer applications used in power systems. A copy of the main menu for our proposed toolbox is presented in Fig. (2). It is an essential requirement of reliable computer programs, that they have some sort of help and debugging systems associated with them. On log/log graph, users have the complete/full flexibility to process all text(s), and curve(s) properties such as adding, deleting, moving, etc … Creation of curves are selected through a *Create Device* pull down menu from the main menu to load a smart pre-designed window for the certain curve creation. Curve may be generated using operators data feeding or with the help of a powerful library associated with specific devices. Easily capture the time/current ordinates by mouse clicking and drag to calculate the time difference to easily achieve the selectivity of curves.
Only MatLab6.0 facilities (Windows) are used to develop and implement the proposed software for power system device selectivity as the MatLab has a great strong library of graphics capability. Executable versions (Running Stand-alone) may be obtained with the relevant DLL files and figures also can be produced after generating C/C++ plus header files code.

The selectivity of protective devices is based on time grading of the device operating characteristics. The time grading is first calculated for the maximum fault level and then checked for lower current levels. The relay closer to the in-feed is time-delayed against the relay away from the in-feed.

Case Study of coordination:
Numerous cases with different sophistication had been tested and analyzed. Here only one a simple case will be detailed and discussed for clarification of toolbox usage only.



I_{fmax}=110*1000/(1.73*11)= 5773.5 A

Step #1 Indicate the maximum short circuit level at 11 kV from *Drawing Options* Menu.

Step #2 Draw the tripping characteristics of extremely inverse relay *Create Curve/Overcurrent Relay/Universal Relay* Menu @ TSM=0.3 & PSM=100% with 200/5 CT ratio.

Step #3 from drawing find the operating time of relay @ max. fault level using mouse position i.e. t_{op}(1)=0.03 Sec of EI Curve.

Step #4 Allow 0.4 time margin the t_{op}(2)=0.03+0.4=43 S for the upstream relay with standard characteristic and then calculate the recommended TSM automatically using the overcurrent proposed module i.e. the program will recommend TSM=0.25. Immediately draw the curve of normal inverse relay (2).

The output graph on log/log as shown in Fig. (3). As there is an intersection/overlap between the relays characteristics then it is concluded that there is partial selectivity between relay and to cope this issue you may use the O/C(2) with same characteristic of O/C (1)

CONCLUDING REMARKS AND FUTURE WORK

A protective devices coordination toolbox using MatLab 6.0 facilities has been developed and implemented. The existing developed toolbox may be run under the MatLab environmental or stand-alone with the complete relevant DLL and Fig files after generating the C/C++ code that may extend the portability feature. Special attentions are paid to the user interface facilities to be easily as possible. Protective devices tripping time/current characteristics of are obtain by a smart series of selection. Our proposed toolbox may be used for educational and commercial purpose as well. On going to embedding a single line diagram drawer to be put on the resulted graph and also to execute the ground fault relays selectivity.

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[7] http://www.powerplot.com.

[8] http://www.mathworks.com.

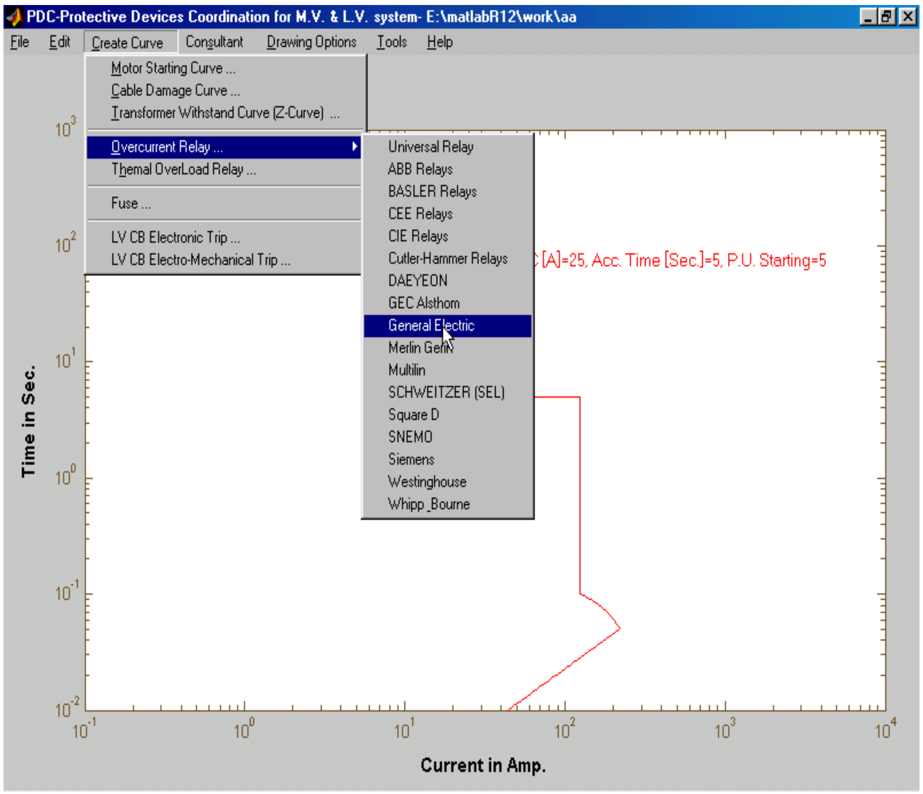

Fig. (2) Main introducing Menu of the overall core

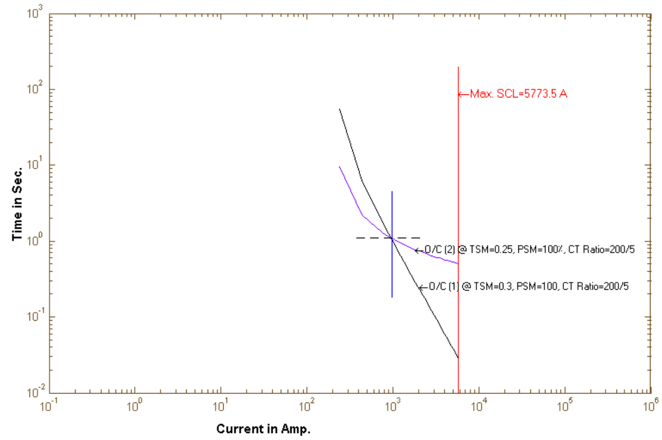

Fig. (3) log/log test case.